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A METHOD OF ACCURATELY REDUCING THE SPIN RATE OF A ROTATING SPACECRAFT

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SUMMARY

A method is presented for reducing the spin rate of a spacecraft to a desired value. Based on the frequently used "yo-yo" system, it features an ability to compensate for deviations of the initial spin rate and moment of inertia from design values. The effectiveness of the system has been empirically verified.

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INTRODUCTION

As more precise instruments have been developed for use in space vehicles, the requirements for governing the orientation and spin of spacecraft have become more stringent. Various methods have been devised to fulfill these requirements. Some of the larger spacecraft are using highly accurate inertia discs and gas jets. Smaller vehicles must use less complex "passive" systems because of their size, weight, and power limitations. Passive orientation systems utilizing the earth's magnetic field or the gravitational gradient of the spacecraft have been developed (Reference 1). Semi-passive systems, utilizing one or more gyroscopes and the spacecraft's own gyroscopic characteristics, have been proposed to produce more effective results.

Most small space vehicles are launched by rockets which are spin stabilized. The problem, then, is to reduce the spacecraft spin rate from the spin rate of the launching vehicle to the desired value–often less than 50 rpm–and maintain this value by minimizing the effects of magnetic damping and the "solar wind."

Several methods have been used to reduce a spacecraft's spin. In cases where it is desired to eliminate the spin completely, magnetic rods can successfully damp the motion by interaction with the geomagnetic field (Reference 2). This method is effective only when: (1) all spin is to be eliminated; (2) the spacecraft is placed in a sufficiently strong magnetic field to achieve de-spin in a reasonable amount of time; (3) a minimum of several hours de-spin time can be tolerated; and (4) the use of magnetic rods is compatible with the operation of the spacecraft.

Small gas jets have also been used to reduce spacecraft spin. These devices are subject to large variations in total impulse. Furthermore, they eliminate a fixed quantity of the spin. Therefore, if the jets function exactly as expected, a 20 rpm error in the initial spin rate will result in a 20 rpm error in the payload's final spin rate. Adverse effects also result from variation in the moment of inertia about the spin axis.

The usefulness of this system is thereby restricted to spacecraft not dependent on an accurate spin rate.

THE RIGID YO-YO

To obtain a greater accuracy than that of either aforementioned system, the Jet Propulsion Laboratory of the California Institute of Technology developed a mechanical spin reducing system known as the yo-yo. In order to differentiate from the method given later in this discussion, this concept shall be referred to as the "rigid" yo-yo.

The rigid yo-yo consists of two weights attached to rigid cords or wires wrapped around the payload in a plane normal to the spin axis, the weights diametrically opposed. At a predetermined time after the satellite has been launched into orbit the weights are released. The cords unwind in the same direction as the payload spins until they reach the radial position, at which time they are released from the spacecraft (Figure 1).

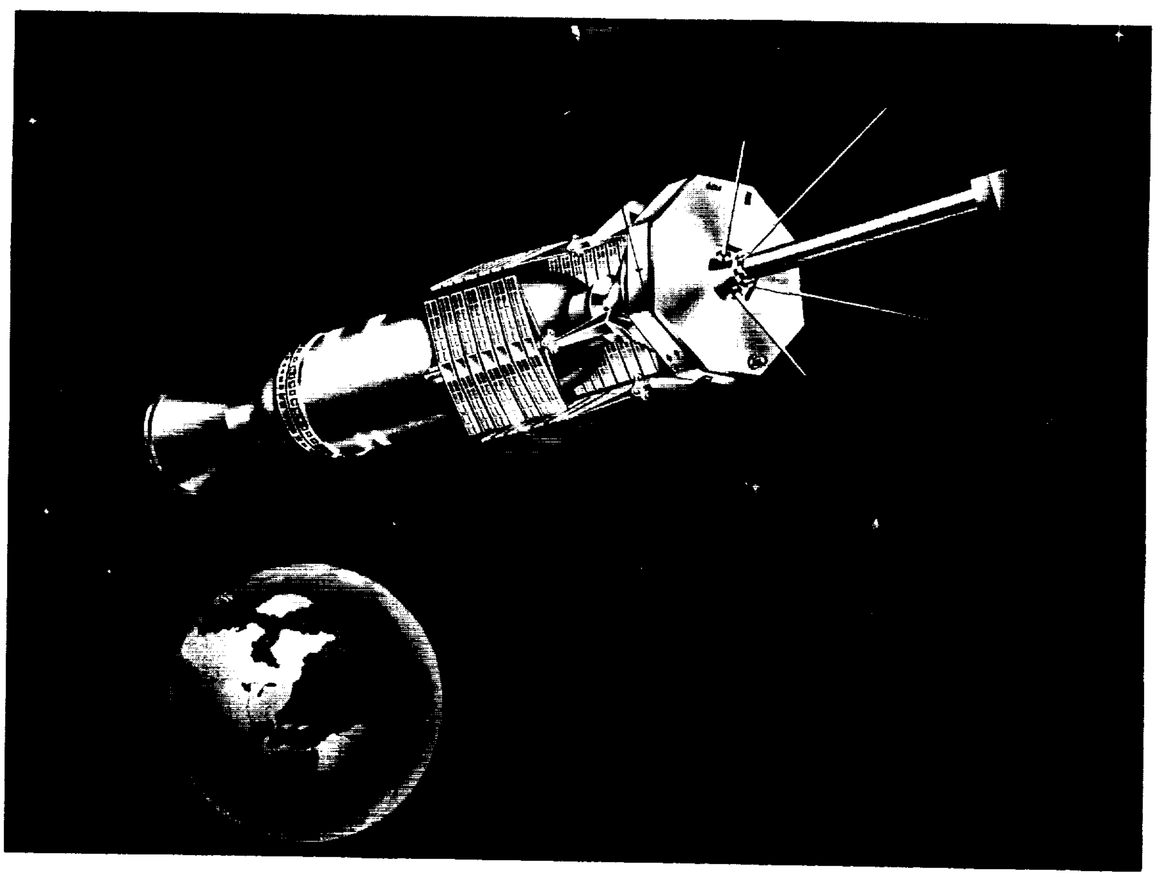

Figure 1—Explorer XII (1961υ) deploying de-spin weights and wires

During this operation angular momentum is transferred to the weights and wires. The momentum transfer gives the following equation (Reference 3):

$$\frac{1 + r}{1 - r} = \frac{I}{m\,(d + a)^2}\,, \tag{1}$$

where

r = spin reduction ratio (final spin rate/initial spin rate),
I = spacecraft moment of inertia about the spin axis,
m = mass of weights plus 1/3 mass of wires,
d = cord length,
a = spacecraft radius.

It is evident from Equation 1 that for a given moment of inertia, the spin reduction ratio r is fixed when the mass m and cord length d are chosen. De-spin to zero can then be accomplished regardless of the initial spin rate, provided the moment of inertia does not vary from the design value. However, in the case of de-spin to some value greater than zero, the error in the final spin rate will be in direct proportion to the error in the initial spin rate.

The variation in final spin rate with respect to the moment of inertia can be more easily seen by rearranging Equation 1. Let

$$m\,(d + a)^2 = C. \tag{2}$$

C is constant when the system has been designed. Then

$$r = \frac{I - C}{I + C}. \tag{3}$$

Figure 2 is the plot of a characteristic variance of r with deviation of the moment of inertia from the design value.

There is often a large tolerance in the spin rate used to stabilize launch vehicles. Furthermore, flight data have indicated that rocket burning can affect the spin rate. This can cause a proportional error in the spacecraft spin rate after the de-spin operation. Some payloads, such as Explorer XII (Figure 1), deploy the yo-yo while attached to the expended last-stage rocket. In this configuration the moment of inertia can vary considerably because of unpredictable burning of the rocket propellant and casing, with results such as those depicted in Figure 2.

It is reasonable, therefore, to expect deviations from the design value in both the initial spin rate and moment of inertia. Thus, the induced errors in the spacecraft's final spin rate may accumulate.

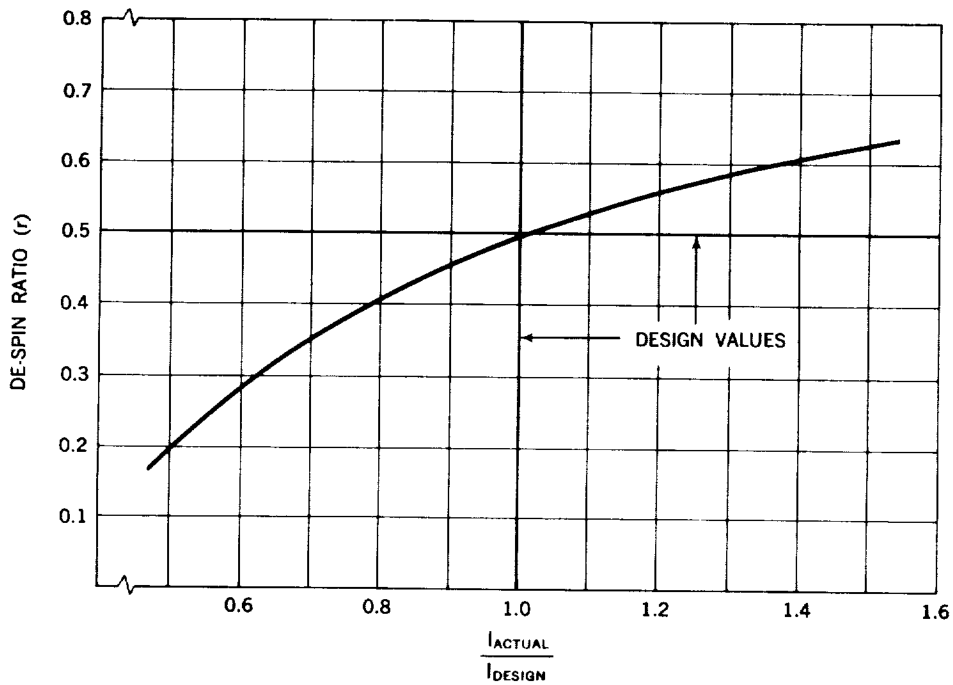

Figure 2—Characteristic variation in de-spin ratio with moment of inertia deviation

THE STRETCH YO-YO

The rigid yo-yo is an uncomplicated, lightweight system. These qualities can be retained and the effectiveness of the system substantially increased, by replacing the rigid cord with an elastic one. This "stretch" yo-yo has the ability to compensate, to a reasonable degree, for errors in the initial spin rate and moment of inertia.

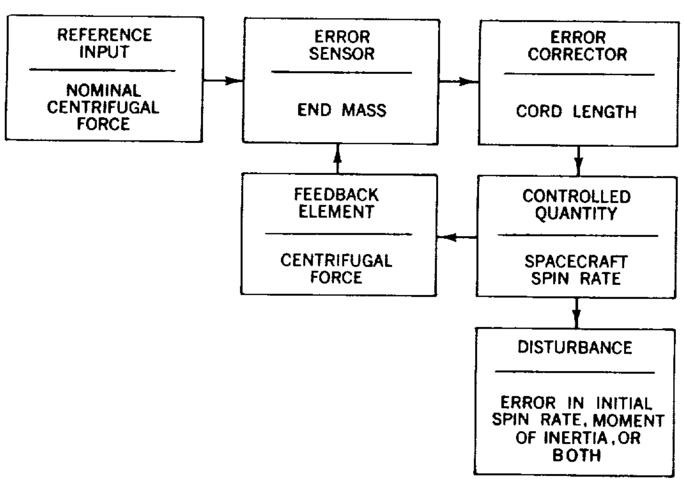

Figure 3—Block diagram of stretch yo-yo servomechanism elements

The stretch yo-yo functions as a simple servomechanism (Figure 3). The centrifugal force on the end mass is a function of the spacecraft spin rate, and the cord length is a function of the centrifugal force. The ability to lengthen or shorten the cord while in operation is thereby built into the system.

An ordinary tension spring can meet the requirements of the elastic cord and, because of its linearity, it can considerably simplify the analytic description of the system. The nominal centrifugal force on the end mass, and the resulting cord length, can then be computed for the case of nominal initial spin and moment of inertia to serve as the reference input.

A theoretical study, in which a spring was used as the elastic cord, yielded the results shown in Figure 4 for a typical de-spin system. The area between the error curves decreased considerably and the extreme deviation—errors of 20 percent in both the initial spin rate and moment of inertia—was reduced by greater than 50 percent.

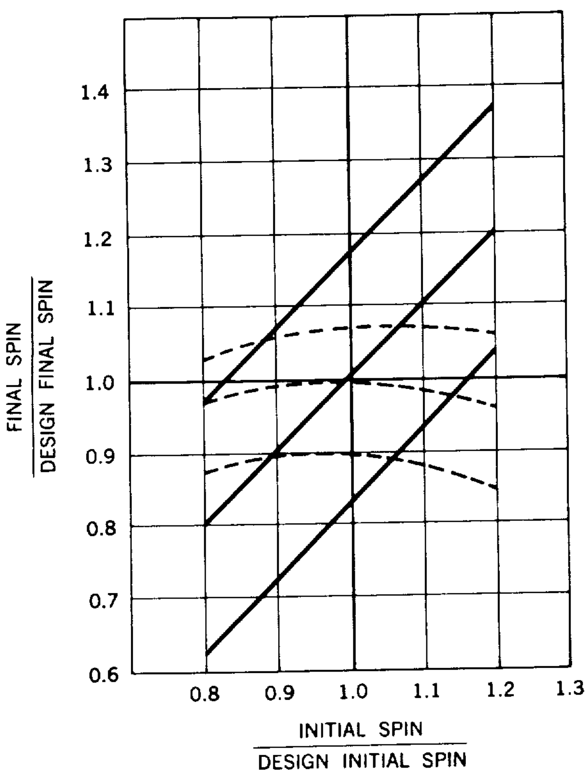

Figure 4—Rigid and stretch yo-yo de-spin characteristics. The solid lines represent rigid yo-yo performance and the broken lines stretch yo-yo performance. The top lines apply at 120 percent nominal inertia, the middle lires at nominal inertia, and the bottom lines at 80 percent nominal inertia.

RESULTS FROM TESTS OF THE STRETCH YO-YO

Two series of tests have been conducted on the stretch yo-yo system. The objective of the first series was to determine the feasibility of the method as applied with typical spacecraft parameters. With these tests successfully completed, the second series was used to develop and qualify a particular system for use on the Ariel I (1962o) ionosphere satellite.

The Langley Research Center 41- and 60-foot vacuum spheres were used to conduct the tests. The test pressure was 10 mm Hg. This essentially eliminated the effects of

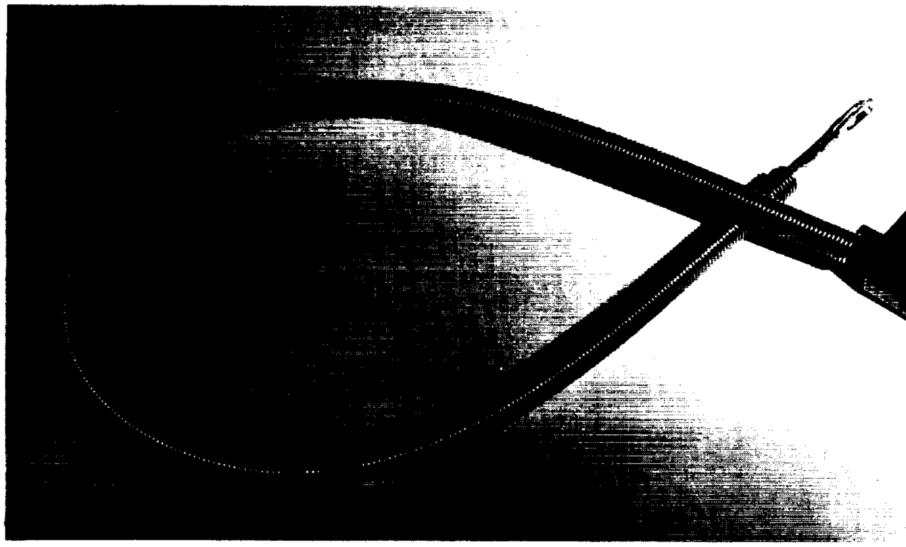

Figure 5—Ariel I stretch yo-yo de-spin spring and end mass

atmospheric drag. The mechanics of the operation were as expected. Figure 5 shows the spring-mass assembly used in the Ariel I de-spin system.

De-spin was in close agreement with the analytically predicted values. A representative plot of the de-spin results, at a given payload moment of inertia, is presented in Figure 6. Rigid yo-yo results which would have been attained with the same payload parameters have been added to the plot for comparison.

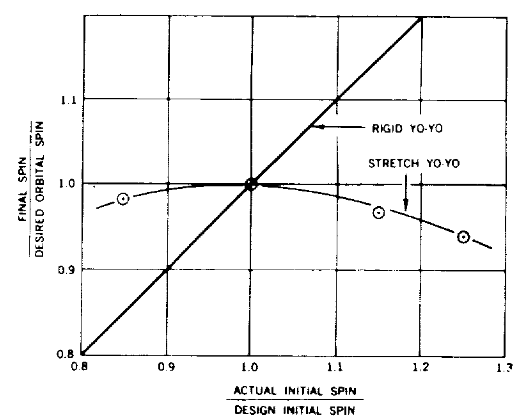

Figure 6—Typical Ariel I stretch yo-yo test results and theoretical rigid yo-yo performance

CONCLUSION

Lightweight spacecraft which require a de-spinning operation will achieve considerably more accurate results by employing the stretch yo-yo system rather than other presently used methods. This increase in effectiveness is gained at no expense in complexity, and therefore a high reliability is retained. A theoretical analysis, and the resulting design criteria, will be published in the future by J. V. Fedor of Goddard Space Flight Center (Reference 4).

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